Hyper Tech

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CHANGING WHAT'S POSSIBLE

Ohio State University

Tennessee Tech University

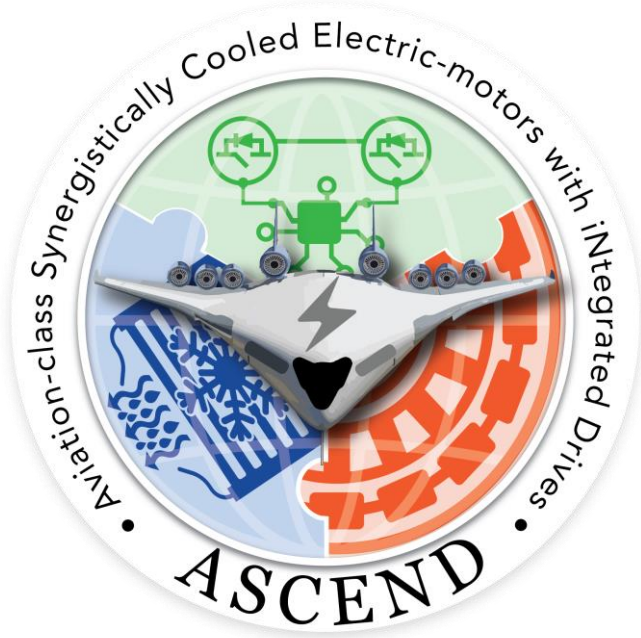
Boeing

Raytheon

U.S. Air Force Propulsion Directorate

DOE grant #DE-AR0001358

Cryo-Thermal Management of High Power Density Motors and Drives Using (Bio) LNG (or Potentially LH2) Fuel for Thermal Management



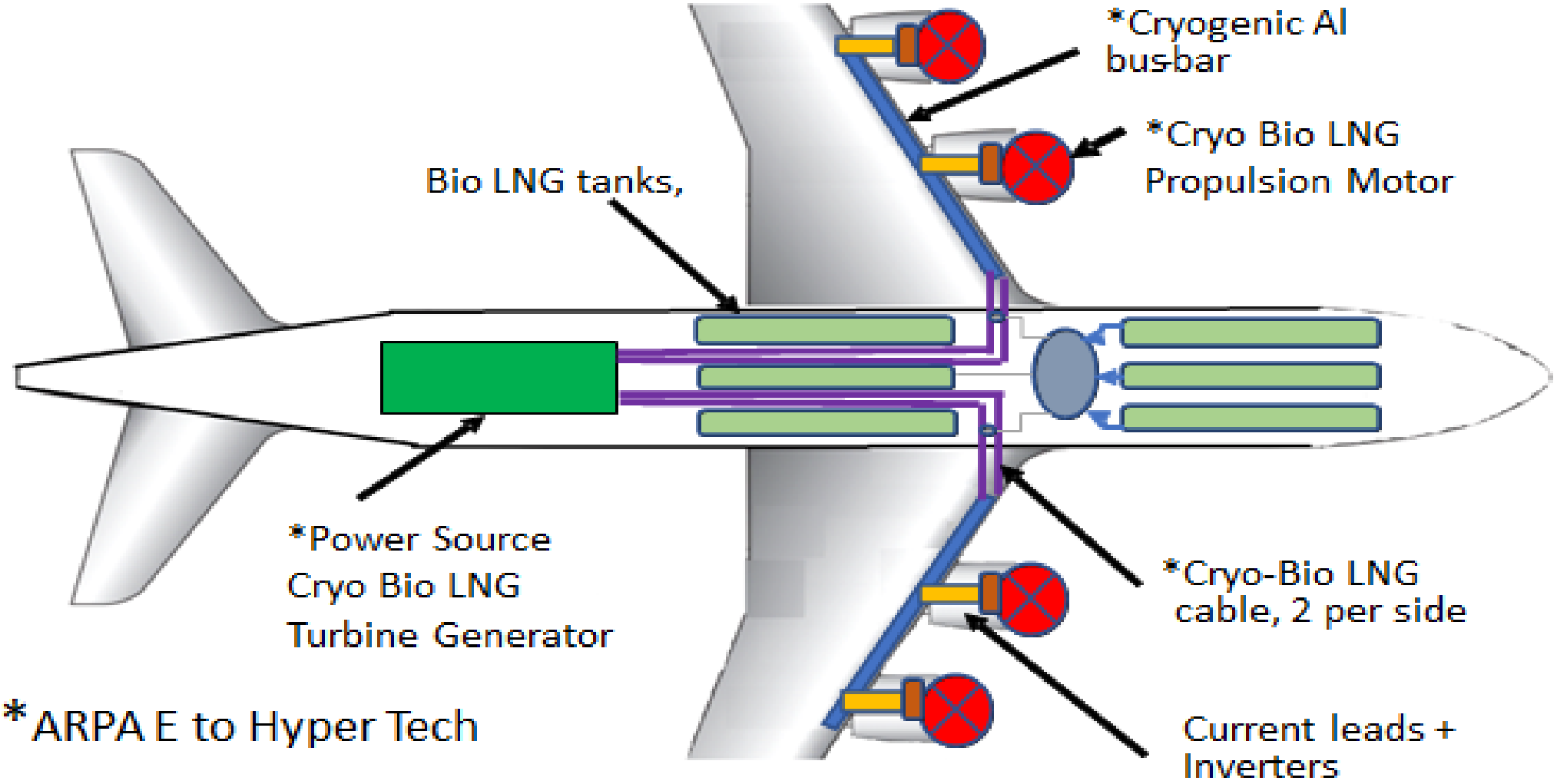
Aviation-class Synergistically Cooled Electric-motors with iNtegrated Drives (ASCEND) program

Project Team

Fed. funding:	$2.9M
Length	42 mo.

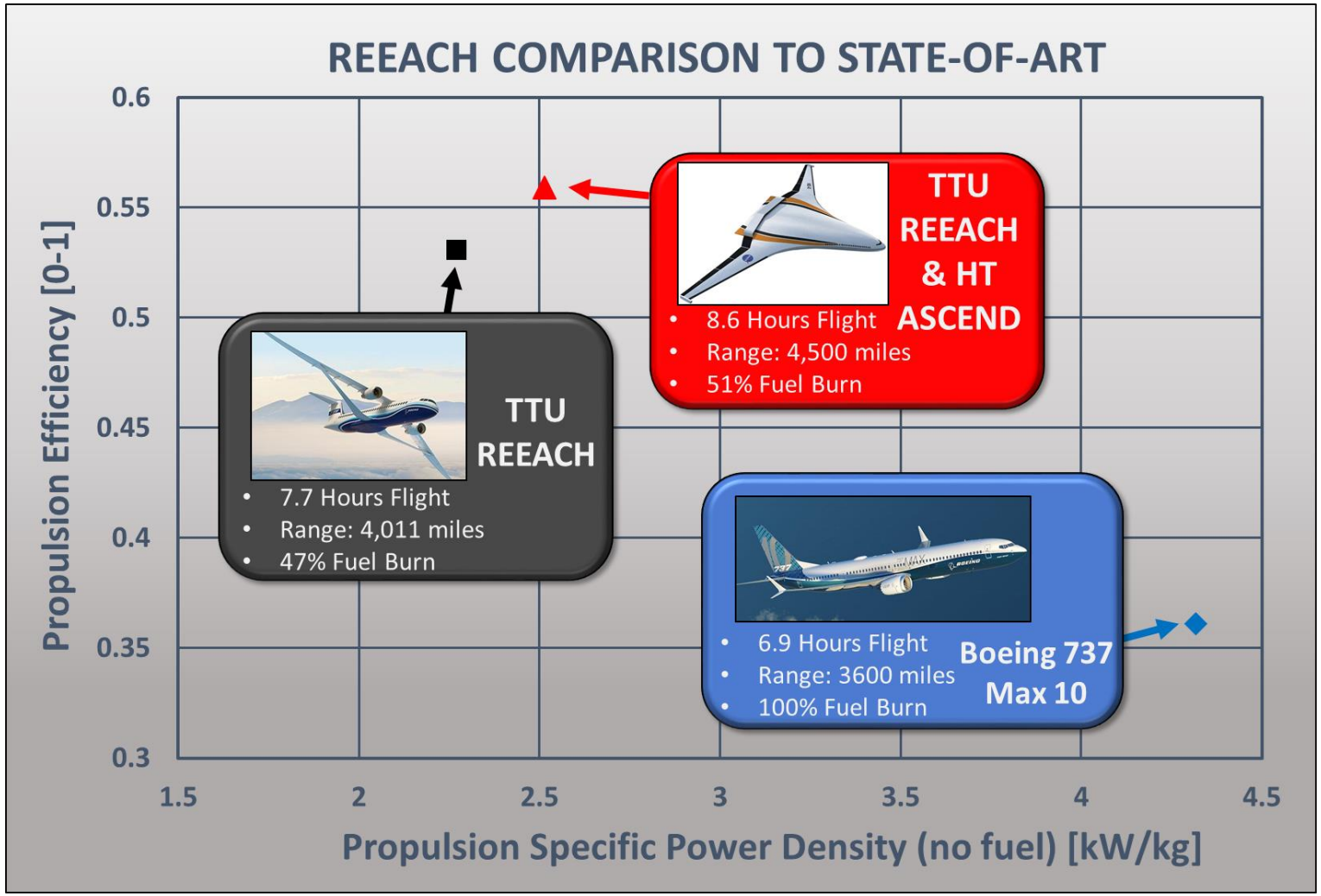
Team member	Location	Role in project
Hyper Tech - Mike Tomsic, David Doll, Dr. Chris Kovacs Matt Rindfleisch	Columbus, OH	Management, Motor and Drive fabrication, Cryogenics, and Superconductors
Ohio State University –Dr. Cordin-Gruie Cantemir , Dr. Michael Sumption, Dr. Milan Marjos	Columbus, OH	Motor and Drive: Modeling, Design and Testing
Tennessee Tech University - Dr. Rory Roberts	Cookeville, TN	Aircraft System Thermal Management Modeling, LNG expertise
Boeing - Dr. John Hull	Seattle, WA	Integration of Motor & Drive System with the turbo-generator system; potential customer
Raytheon – Dr. Parag Kshirsagar	East Hartford, CT	Integration of Motor & Drive System with the turbo-generator system; potential customer
Wright Patterson AFB - Dr. Tim Haugan	Dayton, OH	Aircraft System Expertise, thermal management, LNG &H2 fuel and cryogenics experience

Thermal Management of Complete Drive Train Bio LNG (or LH2)



*ARPA E to Hyper Tech

Summary of REEACH and ASCEND Comparison to State-of-Art



Assumptions:

- Power Gen. Thermal efficiency – 66%
- Power Gen. Specific Power– 3.6 kW/kg

TTU REEACH

- Motor drive specific power -127 kW/kg
- Motor specific power – 12 kW/kg
- Motor efficiency – 93%

TTU REEACH & HT ASCEND

- Motor drive specific power -127 kW/kg
- Motor specific power – 20 kW/kg
- Motor efficiency – 98%

From Dr. Rory Roberts

Comparison Non-Cryo, LNG and LH2 Motors and Drives

System	Requirement: 5000 RPM at takeoff	Non-cryo NASA Completed	Non-cryo NASA Funded	ARPA-E Cryo Funded	Cryo LH2 Design
Total	System capacity Scalable 1-20 MW	1	1.6-2.0	2.1 (3.0)	2-5
	Takeoff (motor, drive, TMS) kW/kg	10	13	17.5-22	63-90
Motor Drive	TMS technology	Liquid cooling	Liquid cooling	120-273K	70 -273K
	Power density (including TMS) at takeoff, kW/kg	60	100	127.5	130
Electric Motor	TMS technology	Liquid cooling	Liquid cooling	Bio-LNG	LH2, 20K + (secondary cooling?)
	Power density kW/kg; Direct Drive, no gear box	12	14	20	70-100

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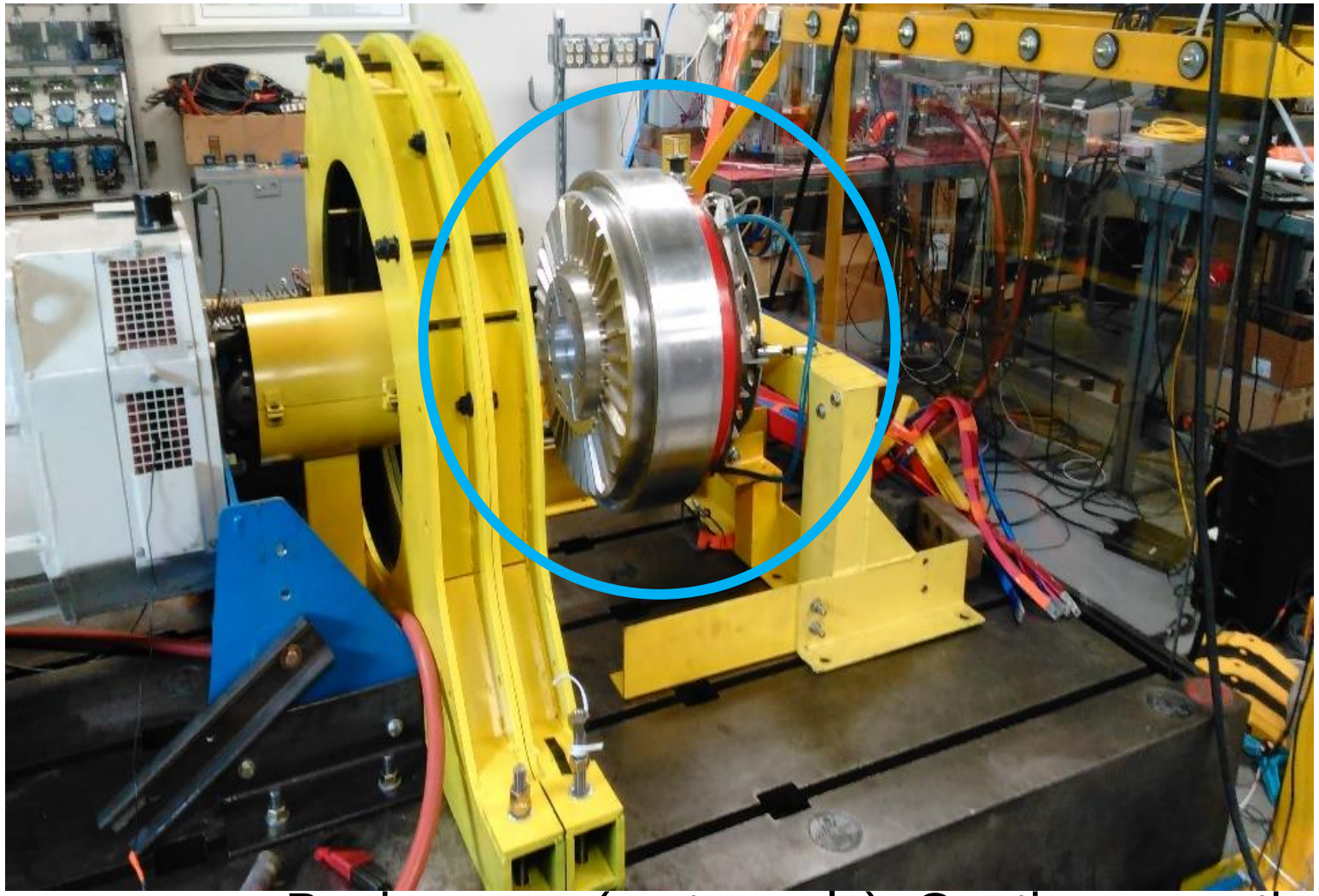
AMBIENT TEMPERATURE MOTOR BUILT FOR NASA HAS BEEN BUILT AND TESTED

THE OHIO STATE UNIVERSITY
CENTER FOR AUTOMOTIVE RESEARCH



This Size approx. 100 kg

1MW -Ambient Temperature

Cryo LNG cooled 2MW plus

Cryo LH2 cooled 6MW plus

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Basic specs (motor only): Continuous rating +1 MW **CONTINUOUS** /5000 rpm, 97.5 kg dry and bare (crane weight)

Why should Aircraft Company Partner with Hyper Tech/OSU

1. **Same Basic Motor Technology applicable to:**
   - A. **Ambient Temperature Design (SAF or Ammonia)**
   - B. **LNG (Bio) Fuel (secondary loop cooling if desired)**
   - C. **LH2 fuel (secondary loop cooling if desired)**
2. **Design is applicable to generators 1-20 MW**
3. **Hyper Tech also doing cryo-cables (LNG & LH2)**
4. **Hyper Tech wants be your complete Drive Train Supplier**
5. **We are out raising investor funds to be your partner in this journey.**

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Benefits of this induction motor and potential generator

1. **Design can be used with both LNG (Bio) and LH2 fuel for propulsion and thermal management**
2. **No permanent magnet! No need to worry about rising prices or availability of rare earth permanent magnets from China**
3. **Induction motor design with high continuous and take-off efficiency**
4. **Uses low cost aluminum and electrical steel**
5. **No electrical insulation uses cryo-fuel (or cryo- liquid) as dielectric**
6. **All materials can be made in the USA**

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Benefits of this induction motor and potential generator

7. Can control temperature of operation of bearings
8. Can control temperature of operation of power electronics
9. Compatible with other cryogenic liquids by using a secondary cooling loop that can be used to transfer heat to cryogenic LNG or LH2 fuel
10. LH2 motors- potential can use superconductors
11. High power density for motors that are scalable to the multiple MW range.
12. High power density generators that are scalable to the multiple MW range.

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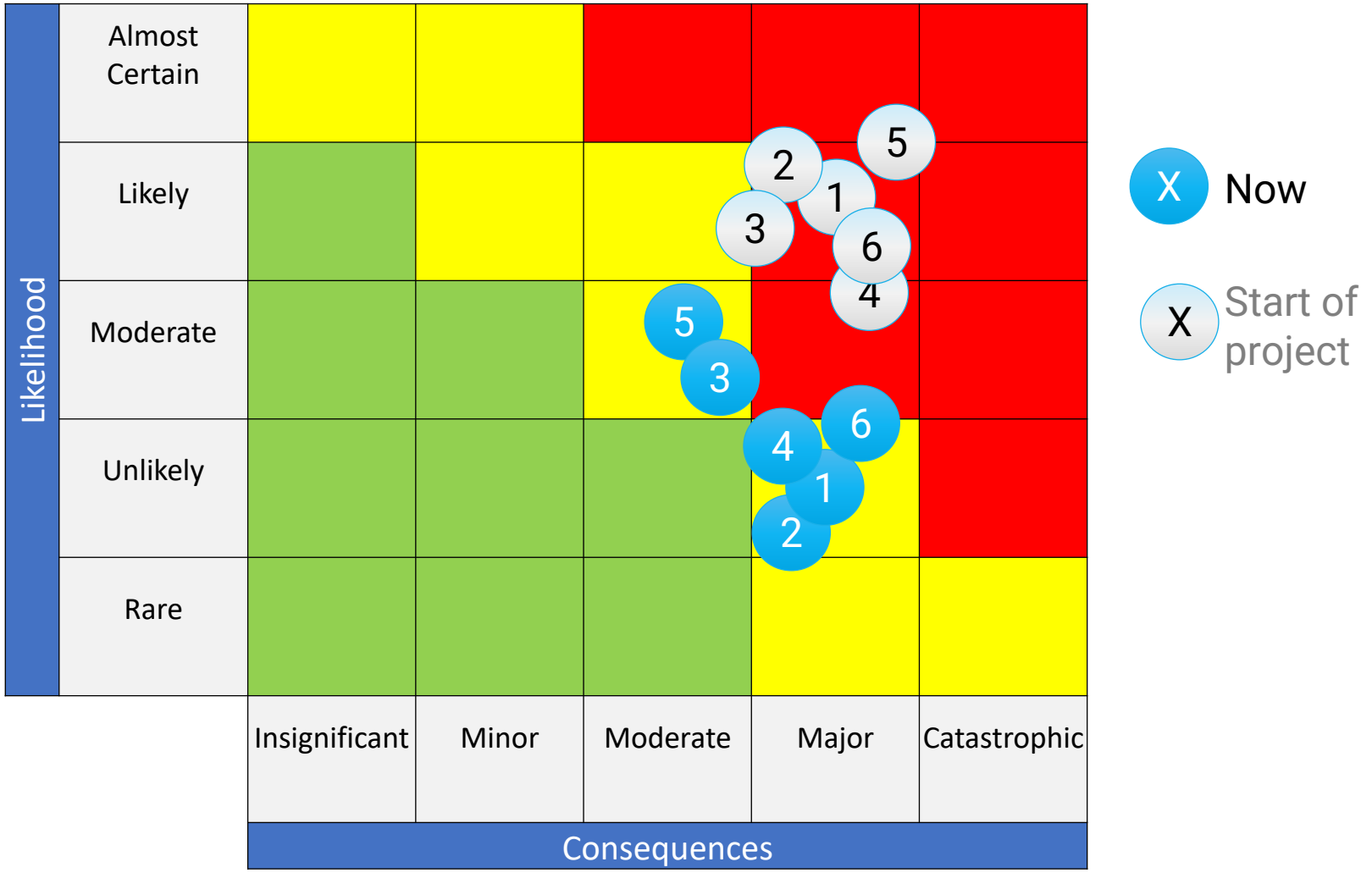
Risk Update

Risk	#
Tech: Rotating Coupling, 5000 rpm	1
Tech: Power Electronics at cryogenic temperatures	2
Tech: Cryo-cooled Al reducing AC losses, 3X higher current density	3
Technical: Meeting the Table 2 requirements	4
Commercial: Convincing market to use LNG as fuel (or LH2)	5
Putting rotor and stator in cryostat	6



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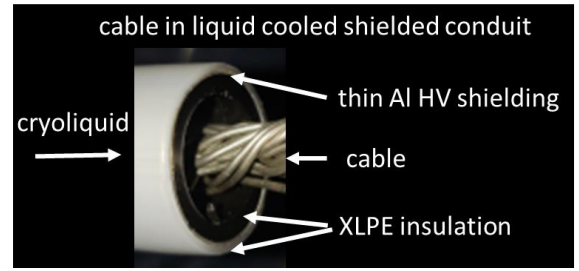
Potential for Cryo-Motors, Drives and Thermal Management Systems

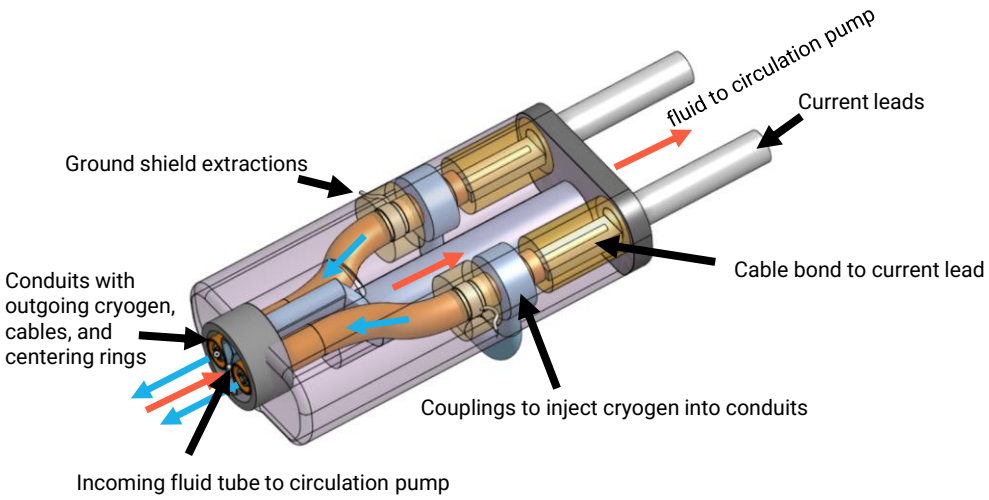
System	Requirement	Proposed Metric	Proposed Metric
2.1 MW (3.0) Electric Motor	Brief description,	cryogenic, Bio-LNG	cryogenic, LH2
	Takeoff and climb average efficiency ,%	97	97+
	Cruise average efficiency, %	98.2	98.2+
	Power density at takeoff (kW/kg;	20.3	70-100
Electric Drive	Takeoff and climb average efficiency, %	98.4	98.4
	Cruise average efficiency, %	98.6	98.6
	Power density at takeoff, kW/kg	127. 5	130
Total System	Takeoff and climb average, efficiency, %	95.5	95.5 +
	Power density at takeoff for the complete powertrain	17.5	60-90

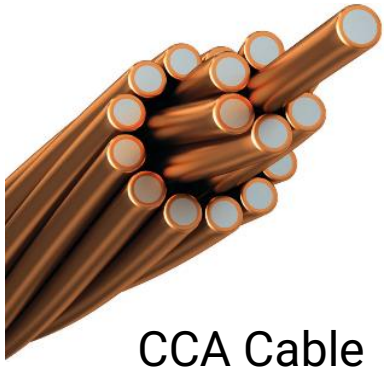
Power Transmission Cable for Electric Aircraft Using Bio-LNG for Cooling and Thermal Management

Objective: We are creating lightweight, easily configurable, and highly robust aerospace power distribution using cryo-resistive (non-superconducting) cables which utilize cryogenic fuel to directly or indirectly cool the cable for increased ampacity.

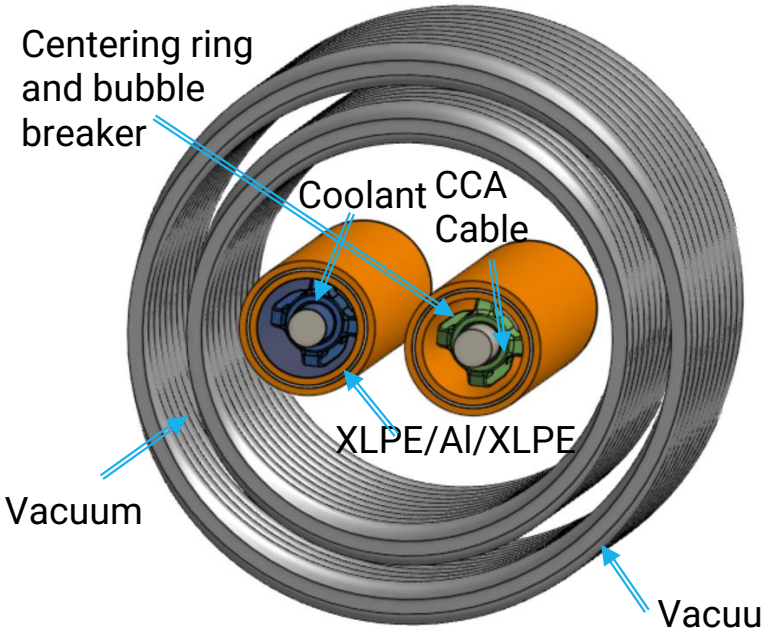
- Our design is a 10s of meter long, ground-shielded, force-flow cooled, cryo-resistive cable with cryogenic coolant turn-around at terminations.
- Novel use of a XLPE-Al-XLPE cryogenic conduit with dielectrically compatible cable centering rings which double as bubble breakers.
- Low kg/m/kA compared to COTS power cables. At higher amperages, which permits lower voltages, cryo-resistive cables perform even better versus COTS cable.







CCA Cable



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Technology-to-Market Approach

Our Plan is to commercialize technology developed via the ASCEND program

- Hyper Tech plans to sell Motors both Ambient and Cryo-Cooled.
- Hyper Tech plans to sell in the future Cryo-Cooled Cables and Cryo-Cooled Generators.
- We want to manufacture components including parts for rotor, stator, cryogenic systems, cryogenic enclosures, dewars, vacuum jacketed piping, etc.
- We intend to sell into the ship and train motor markets that will be using LNG or LH_2 as cryogenic fuels for transportation.
- We want to make sure our components are compatible with LNG and LH2 fuels, but can also use non flammable cryogens as secondary loop cooling if desired.

What are the anticipated first markets?

1) Motors for small aircraft (0.5 – 3 MW) range using LNG or LH2 fuel.
2) Other early markets will be LNG and H2 motors for ships, trains and trucks

What are the anticipated long-term markets?

The single and double aisle passenger aircraft, motors 0.5-5 MW, cryo-cables, and generators 5-20MW

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Technology-to-Market Approach

Next Level Projects –who wants to partner with us on the follow types of projects.

- Layout and design of a complete drivetrain. (ambient, cryo LNG, or cryo- LH2)
- Next cryo-motor demonstration (Size ? Type?) - do a Flight Demo
- Demonstrate the cryo-motor and cryo-cable at the same time
- Develop and demonstrate an ambient or cryo-generator -1 MW
- Demonstrate an ambient or cryo-generator 10-20MW
- Design, develop, and demonstrate a complete drivetrain system- in the Laboratory
- Build a complete drivetrain system – Flight Demo

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